Massively Scalable Mixture Model for Small-scale Sand Ripples

Joseph Calantoni
Marine Geosciences Division
Naval Research Laboratory
Code 7440.3, Building 1005
Stennis Space Center, MS 39529
phone: (228) 688-4435 fax: (228) 688-4853 email: joe.calantoni@nrlssc.navy.mil

Allison M. Penko
Marine Geosciences Division
Naval Research Laboratory
Code 7440.3, Building 1005
Stennis Space Center, MS 39529
phone: (228) 688-4823 fax: (228) 688-4853 email: allison.penko@nrlssc.navy.mil

Award Number: N0001409WX20750
http://www7400.nrlssc.navy.mil/index.htm

LONG-TERM GOALS

Our long-term goal is to develop a modeling framework to predict sediment transport, the evolution of seafloor roughness, and acoustic propagation through the seafloor in the nearshore and littoral battlespace environment.

OBJECTIVES

Our primary objective is to implement a massively parallel version of an existing mixture model, SedMix3D (Penko and Slinn, 2006), for simulating small-scale ripple dynamics in shallow littoral environments. Applicability of the existing serial version of SedMix3D is severely hampered by physical limitations (memory and CPU speed) of typical desktop workstations. The scalable version of SedMix3D developed here will be able to simulate prototype size domains found in the center of a laboratory U-tube (up to 1 m in length). The parallel version of SedMix3D is a powerful research tool that will be used to study the details of small-scale sand ripple dynamics including (1) the effects of suspended sediment concentration on turbulence modulation, (2) the dynamics of ripple transitions from 2D to 3D (and back to 2D) under changing forcing conditions, and (3) the role of terminations and bifurcations on ripple migration and growth rates.

APPROACH

SedMix3D treats the fluid-sediment mixture as a single continuum with effective properties that parameterize the fluid-sediment and sediment-sediment interactions using several closures for the sediment phase. The capability of SedMix3D to simulate small-scale sand ripple dynamics has been illustrated both qualitatively and quantitatively (Penko and Slinn, 2006; Penko et al., 2008).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**
4. TITLE AND SUBTITLE **Massively Scalable Mixture Model for Small-scale Sand Ripples**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,Marine Geosciences Division,Code 7440.3, Building 1005,Stennis Space Center,MS,39529**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S)
		11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Unfortunately, the most rigorous quantitative comparisons between the model and existing laboratory data have been performed only using domains that are essentially 2D. The expensive computational costs coupled with hardware limitations on typical desktop workstations have limited the largest scale 3D simulation performed with the serial version of SedMix3D to date to a domain about 12 cm in length, which required 75 days of computations to simulate just about 9s of real time. Utilizing HPC resources available through an ongoing NRL 6.1 base project, we seek to increase the domain size by up to an order of magnitude while reducing the wall-clock run times by up to 2 orders of magnitude, running on processor arrays from 64 up to a maximum available of 2048 cores on the Cray XT3 at the ERDC DSRC and the Cray XT5 at the NAVY DSRC.

WORK COMPLETED

We have recently completed parallelization of the SedMix3D code using the message-passing interface (MPI). Preliminary simulations have been performed on processor arrays up to 512 cores on the Cray XT3 at the ERDC DSRC. We have achieved our goal of simulating prototype size domains, with the largest simulation to date roughly covering a ~ 1 m^2 sand bed (Figure 1). We have conducted initial performance scaling tests and rigorous quantitative validation of the simulation output is underway.

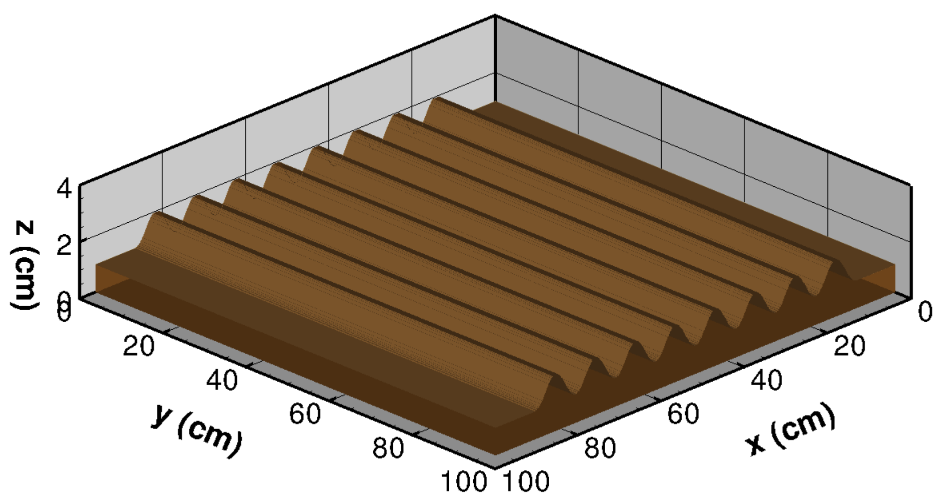
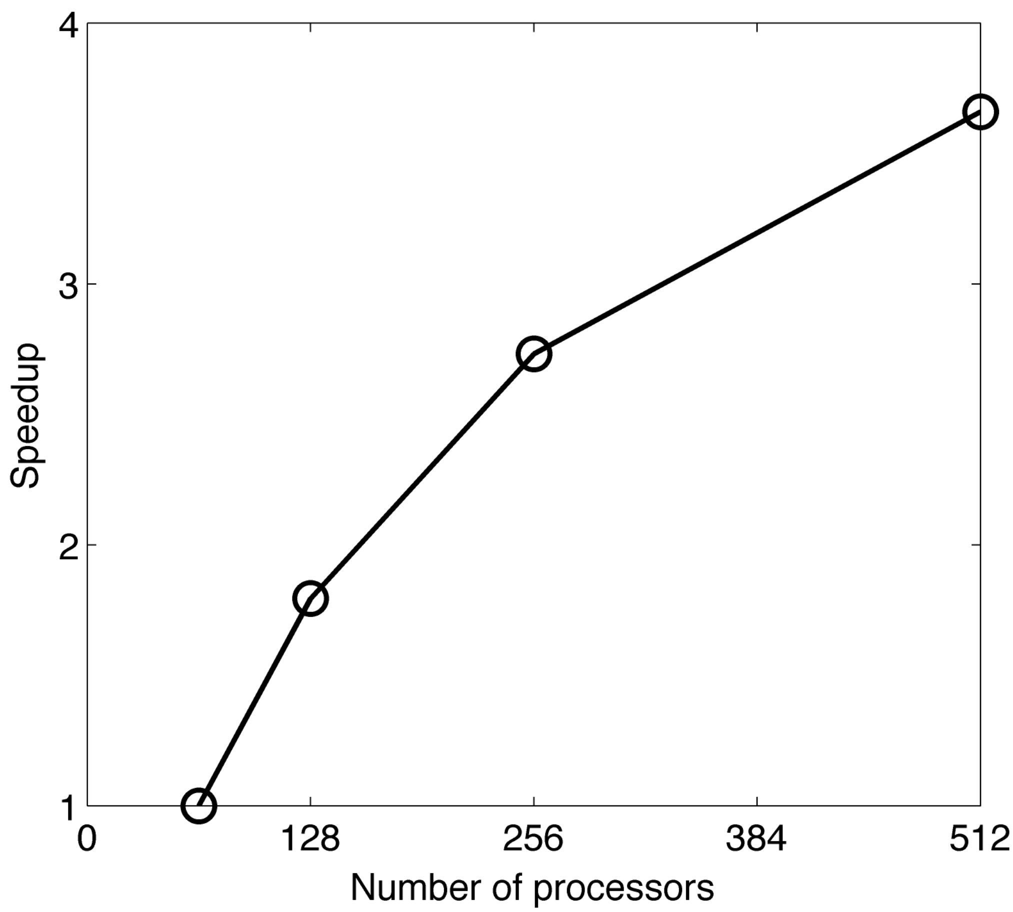


Figure 1. Initial sediment bed of parallelized three-dimensional SedMix3D numerical model. The domain is initialized with 8 ripples with 1 cm heights and 10 cm wavelengths on a 1 cm packed bed. The grain size diameter of the sediment is 0.4 mm. Only 4 cm of the 16 cm domain height is shown here. The flow over the ripples can be oriented at varying angles to observe three-dimensional ripple evolution.

RESULTS

We recently performed a fixed scaling speedup test using the simulation domain shown in Figure 1. The new parallel version of SedMix3D was run with arrays of 64, 128, 256, and 512 cores on the Cray XT3 at the ERDC DSRC. The scalability of the code up to 512 cores is very encouraging, resulting in approximately 3.5 times speedup over 64 cores. We expect that continued scalability will require more sophisticated I/O algorithms. As the number of cores increases it becomes exceedingly difficult and time consuming to write results to disk. We will continue testing and validation of the parallel version of SedMix3D with high-resolution laboratory data in FY10.



SedMix 3D is parallelized using Message-Passing Interface (MPI) programming. Shown is a plot of the increase in computational speedup running a fixed size problem on an increasing number of processors. The code runs approximately 3.5 times faster on 512 processors than on 64 processors.

IMPACT/APPLICATIONS

The research tool developed here will be used to improve understanding of bedform dynamics, and more generally, bottom boundary layer physics in shallow sandy environments. We expect the results to impact broadly both Naval operations (e.g., littoral navigation and trafficability including surf zone breaching, MCM, and characterization of both the air-sea boundary layer and the bottom boundary layer in the battlespace environment) and commercial activities (e.g., coastal restoration procedures and design of coastal infrastructure).

RELATED PROJECTS

The PI is the lead investigator for an NRL 6.1 base project (FY08-FY10), titled "Direct Numerical Simulation of Small-scale Sand Ripples". The parallel version of SedMix3D developed here is being used in direct support of the NRL base project. Likewise, all HPC resources used to perform the work funded by ONR were provided by NRL. Additionally, the model and simulation results produced here form the basis for the Ph.D. dissertation (expected August 2010) of student, Ms. Allison M. Penko, University of Florida. Presently, Ms. Penko is working at NRL under the Student Temporary Employment Program (STEP).

REFERENCES

Penko, A.M., and D.N. Slinn (2006), Modeling sand ripple evolution under wave and current boundary layers, *Proceedings of the 30th International Conference on Coastal Engineering, ASCE*, San Diego, CA.

Penko, A.M., Slinn, D.N., and D.L. Foster (2008), Model-Data Comparison of Sediment Transport over Evolving Rippled Beds, *Ocean Sciences Meeting*, Orlando, FL.

PUBLICATIONS

Penko, A.M., Calantoni, J., and D.N. Slinn (2009), Mixture theory model sensitivity to effective viscosity in simulations of sandy bedform dynamics, *Proc. IEEE Oceans 2009, OCEANS*, Biloxi, MS. [in press]